Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Project

EDL Engineering Constraints

Mars 2020
1st Landing Site Workshop

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Overview

- Given the “re-flight” nature of Mars 2020, the EDL engineering constraints unsurprisingly look a lot like MSL’s engineering constraints with a few exceptions

- The 2020 opportunity enables higher landing site elevations than were possible with MSL

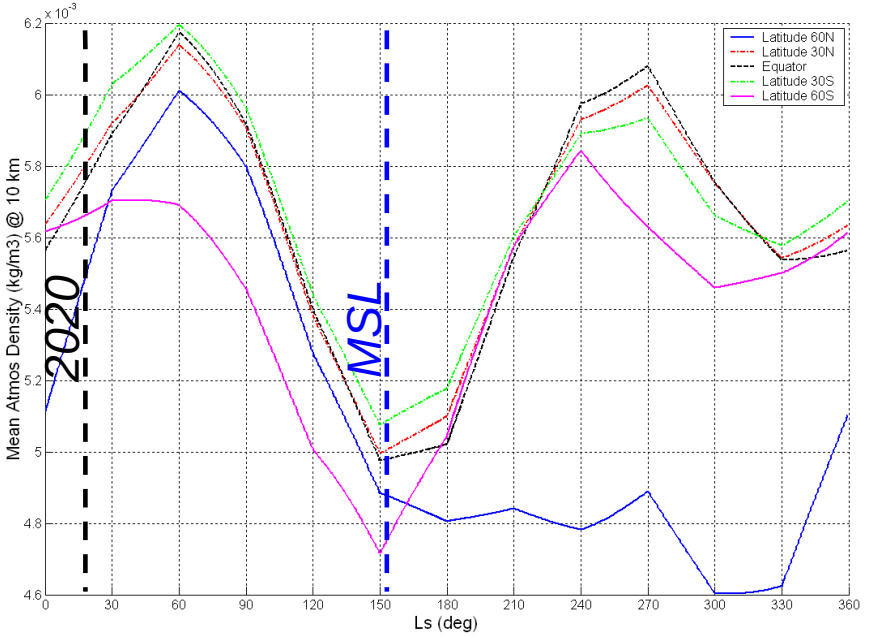
- Engineering constraints are a discretized set of thresholds
  - Some of these are firmer than others
  - Constraints are interconnected
  - We’ve got a better handle on this now after MSL

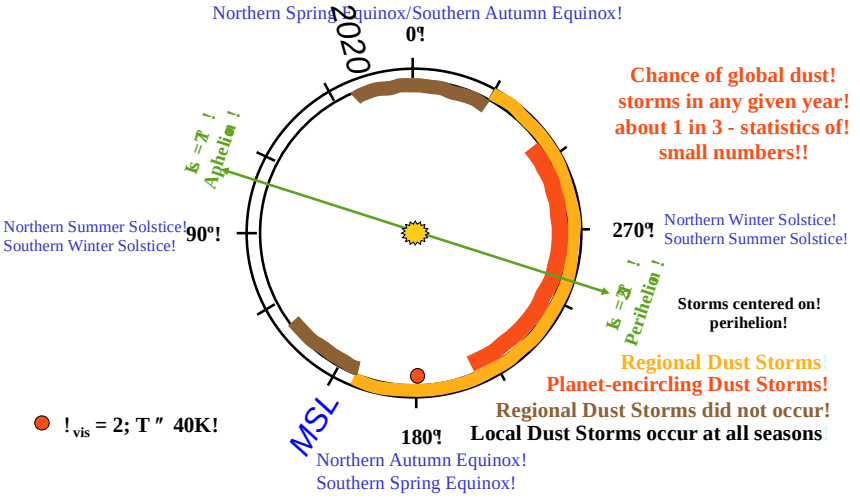
- Potential enhancements to EDL are being considered: Range Trigger and TRN
  - Improves landing site access
  - Will affect engineering constraints

- This primer refreshes the MSL constraints for Mars 2020

EDL in the 2020 Opportunity

- Pressure cycle very favorable for 2020
  - Mars orbit eccentricity transfers CO_2 from polar caps to atmosphere
  - Atmosphere significantly more dense than for MSL landing
  - Low risk of dust events
- More density = capability to land safely at higher elevations
- 2020 atmosphere provides *significant "no cost" improvements* to landing elevation for same landed mass
  - Higher altitude capability
  - More propellant margin





Baseline Engineering Constraints

- Our understanding of MSL capabilities has matured
- Mars 2020 baseline EDL engineering constraints reflect our best knowledge of the MSL as-flown capability translated to the 2020 opportunity
- 2020 opportunity improves altitude capability; other constraints unchanged from MSL as flown
- Constraints will look very similar to original MSL constraints with a few exceptions
- Following slide summarizes the Mars 2020 baseline constraints

EDL Constraint Summary

	MSL Capability (in 2011 opportunity)	Mars 2020 Baseline	Notes
Ellipse Size (major x minor)	25 km x 20 km		No change from MSL.
Site Elevation	Up to -1 km MOLA	Up to +0.5 km MOLA	2020 opportunity improves elevation capability.
Latitude	30° S to 30° N		No change from MSL.
Approximate Ellipse Major Axis Azimuth	N/A	81° - 112°	
Rocks	≤ 0.5% chance of rock > 0.55 m high in belly pan area Corresponds to ~8% rock abundance (Can be significantly higher for portions of ellipse)		No change from MSL. Approximate MSL test/analyzed capability. Portions of MSL landing site candidates had local CFA of ~30%.
Rover Scale Slopes	≤ 30° at 2 m length scales		Increased from original MSL specifications; within as flown capability.
Allowable Hazardous Areas in Ellipse	N/A		
Allowable Relief (5 m to 1000 m Baseline)	≤ 100 m relief		Increased from original MSL specifications; within as flown capability
Radar Reflectivity	Ka-band reflective		No change from MSL.
No Thick Dust Deposits	>100 J m^{-2} $s^{-0.5}$ K^{-1} and albedo < 0.25		No change from MSL.
Load Bearing Surface	Surface must be load bearing to prevent sinkage during touchdown		No change from MSL.
Atmosphere	Up to 25 m/s horizontal and 20 m/s vertical wind uncertainty		No change from MSL.

Potential Enhancements

- Mars 2020 is studying two potential EDL enhancements, as discussed in the SDT report
  - Range trigger: improves landing precision (smaller landing error ellipse)
  - TRN: allows some hazards in the landing ellipse

- Neither option is currently baselined
  - Looking for feedback on the value/necessity of each
    - Does either approach (or their combination) allow access to a high-value site that is inaccessible with the baseline capability?
    - Does either approach (or their combination) change a site accessible only by “go to” into a “land on” candidate?
  - Will look at landing hazards presented by landing site candidates

- Ongoing studies are giving us a better understanding of the costs and potential landing site access benefits

Range Trigger

- Trigger parachute deploy based on the vehicle reaching a navigated *range* rather than a navigated *velocity*
  - MSL baseline: deploy the parachute based on reaching a specified navigated velocity (a.k.a. “velocity trigger”)
  - Range trigger: deploy on range within safe velocity limits (sometimes called “velocity constrained range trigger”)

- To successfully execute guided entry, the vehicle already propagates its position from the pre-entry nav state
  - MSL “knew” it was long of the center of the ellipse when it deployed the parachute, but couldn’t do anything about it

- No new hardware is required – only a simple EDL flight software change

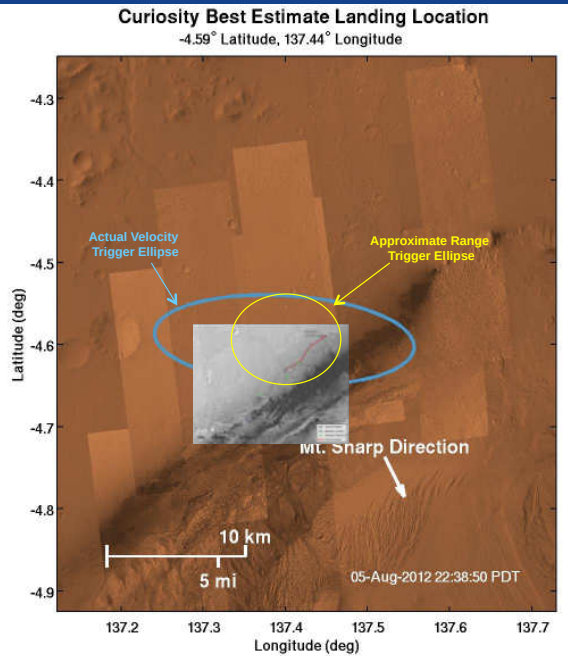
Improves Landing Precision

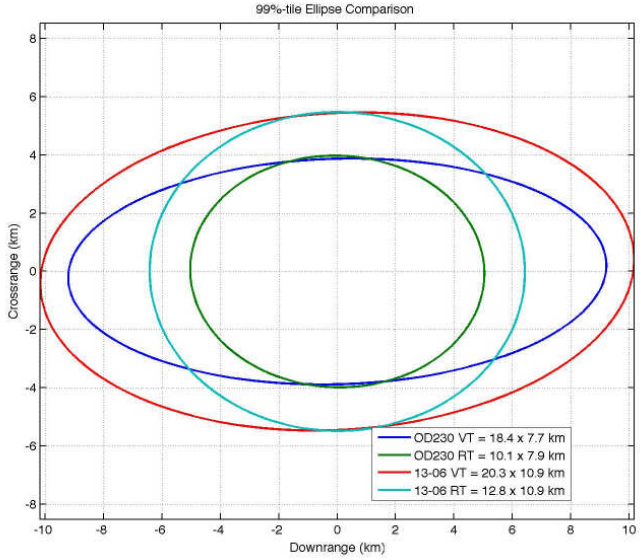
- Using range trigger can significantly shrink the landing ellipse
  - ~40% reduction in ellipse area
  - ~8 km reduction in ellipse length
  - Magnitude of the improvement depends on landing site wind uncertainty and site elevation

- Given conservative engineering wind constraints, willing to sign up for **16 km x 14 km ellipse**
  - Best estimate: 12 x 11 km with MSL Gale-like winds
  - Baseline: 25 km x 20 km

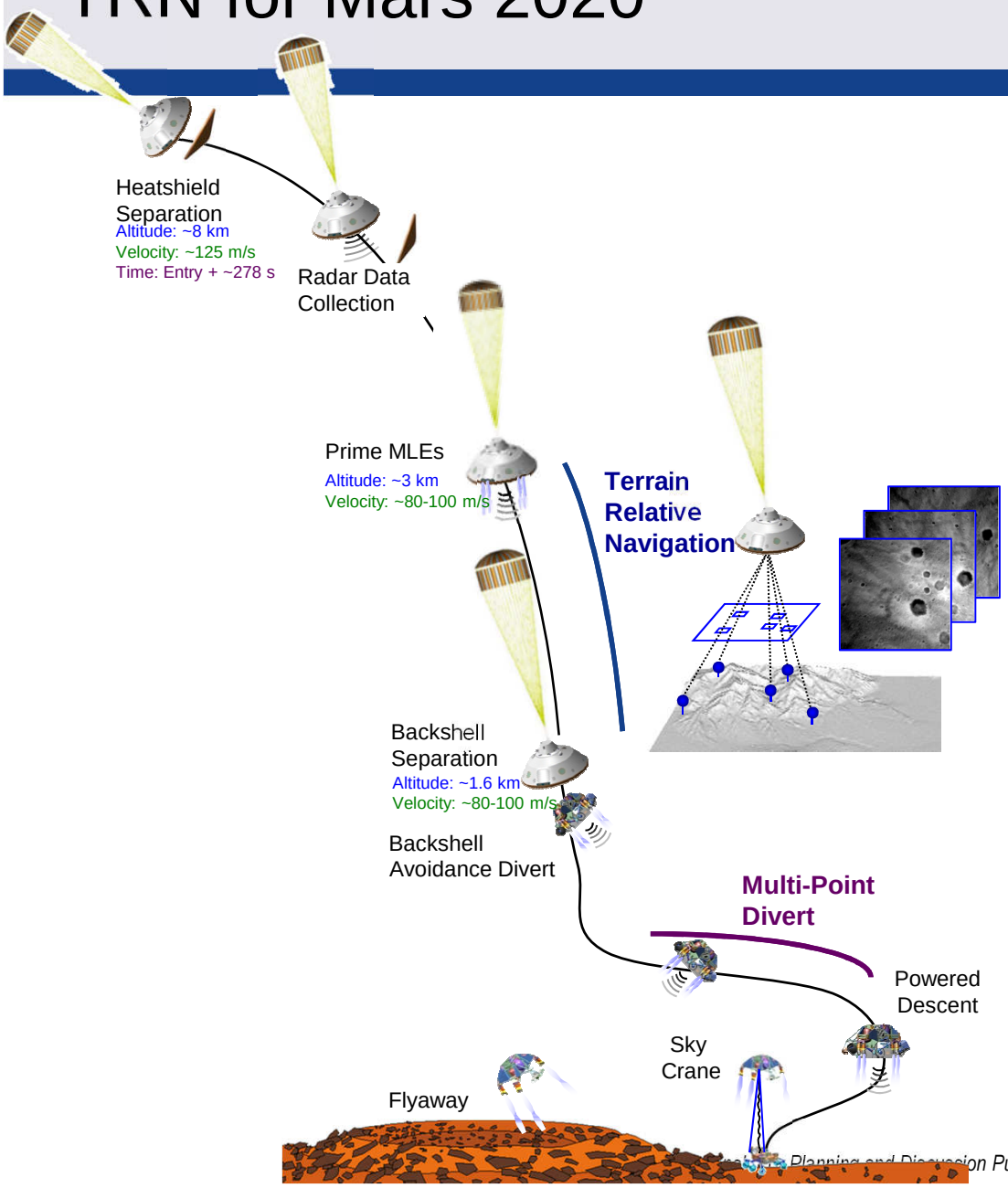
- Maximum site elevation with range trigger: 0.0 km MOLA

- Key benefits:
  - Makes previously inaccessible landing sites accessible
  - Could save ~1 Earth year of driving
  - Makes the TRN job easier





TRN for Mars 2020



Terrain Relative Navigation

- Works by taking images during parachute descent and matching them to an onboard map
  - Uses a dedicated compute element, camera, and (maybe) an inertial measurement unit
  - Yields a position solution
- Performs terrain relative navigation while the spacecraft is priming the descent engines
- Executed by the Lander Vision System (LVS)

Multi-Point Divert

- Uses position solution and list of safe landing locations to select a landing target
- Augments original MSL backshell avoidance divert (requires slightly higher backshell separation altitude)
- Lives within MSL fuel and control authority constraints

Preliminary Landing Site Access Results with TRN

Partial List of SDT Suggested Landing Sites	Baseline (No TRN)	TRN with 40 m Accuracy	TRN with 60 m Accuracy	Comments
NE Syrtis Major	87.0%	99.5%	98.6%	
E Margaritifer	87.8%	98.6%	97.1%	
Nili Fossae*	95.5%	99.7%	99.4%	
Ismenius Cavus	81.6%	94.2%	92.3%	Significant improvement likely w/ range trigger ellipse
Holden Crater Land-On Target*	96.1%	99.8%	99.6%	See next slide

* Assumes a 14x16 km range trigger ellipse at touchdown

- TRN yields significant improvement in likelihood of safe landing
  - Maximum site elevation for TRN capability: approximately -1.0 km MOLA
  - Magnitude of improvement higher with better localization accuracy
  - Accuracy worse than 60 m greatly diminishes value of TRN

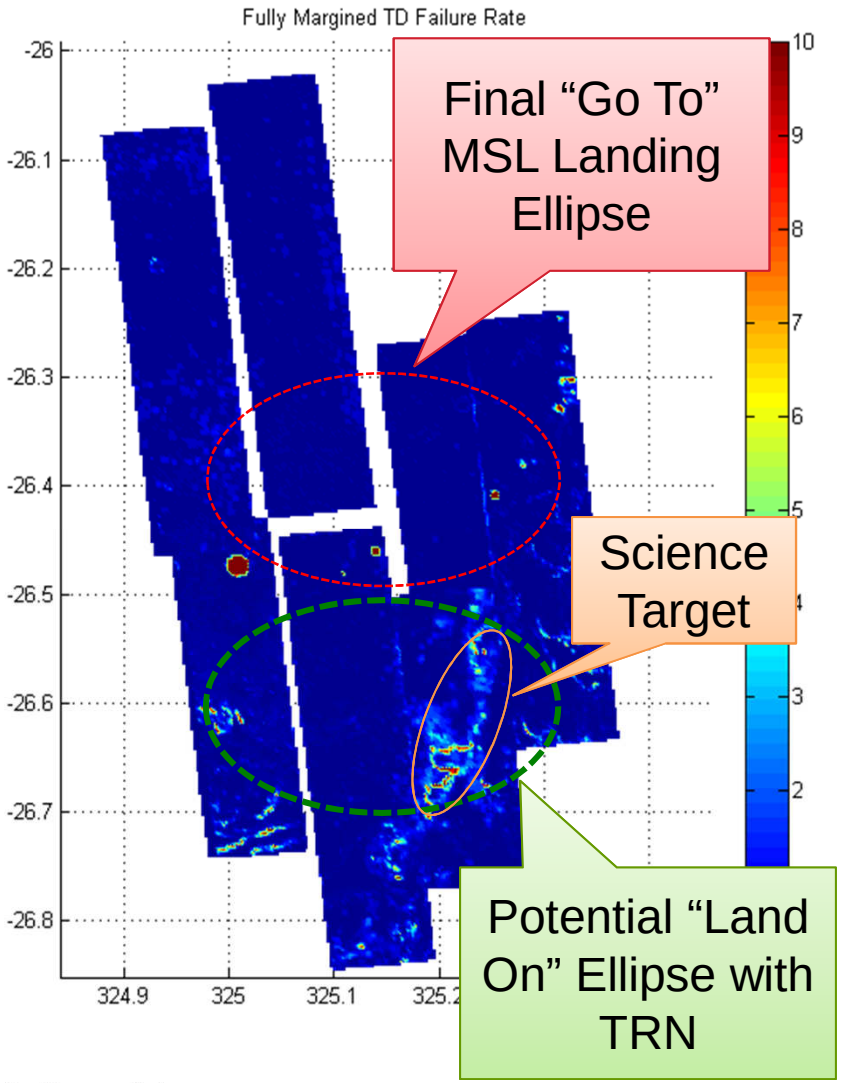
- For comparison: At time of selection, MSL final four landing site candidates all ~99% safe with respect to landing hazards

TRN and Go To vs. Land On

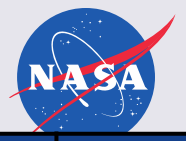
- Used Holden (MSL landing site finalist) to investigate converting a "go to" site to a "land on" site with TRN

- At Holden, TRN allows the ellipse to be moved down onto the go-to target
  - Minimal increase in terrain failure rate
  - ~12 km shift in center of ellipse

- May not work at all sites, but worth exploring for 2020 candidates



EDL Constraint Summary



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	MSL Capability (in 2011 opp.)	M2020 Baseline	M2020 with Range Trigger	M2020 with Range Trigger + TRN	Notes
Ellipse Size (major x minor)	25 km x 20 km	25 km x 20 km	16 km x 14 km		Range trigger ellipse may be as small as 13 km x 7 km
Site Elevation	Up to -1 km MOLA	Up to +0.5 km MOLA	Up to +0.0 km MOLA	Up to -1.0 km MOLA	2020 opportunity improves capability
Latitude	30°S to 30°N				
Approximate Ellipse Major Axis Azimuth	81°- 112°				
Rocks	≤ 0.55 m in height			Exempt from rock/rover scale slope constraints in hazardous areas. Constraints apply in “safe” areas.	
Rock Cumulative Fractional Area	≤ 0.5% chance of rock > 0.55 m high in belly pan area; corresponds to ~8% rock abundance (Can be significantly higher for portions of ellipse)				Approximate MSL test/analyzed capability. Portions of MSL landing site candidates had local CFA of ~30%.
Rover Scale Slopes	≤ 30° at 2 m length scales				Increased from original MSL specifications; within as flown capability
Allowable Hazardous Areas in Ellipse	N/A			≤ 110 m radius Separated from other hazardous areas by ≥ 120 m	New capability only provided by terrain relative navigation
Allowable Relief (5 m to 1000 m Baseline)	≤ 100 m relief				Increased from original MSL specifications; within as flown capability
Radar Reflectivity	Ka-band reflective				No change from MSL.
No Thick Dust Deposits	>100 J m^{-2} $s^{-0.5}$ K^{-1} and albedo < 0.25				No change from MSL.
Load Bearing Surface	Surface must be load bearing to prevent sinkage during touchdown				No change from MSL.
Atmosphere	Up to 25 m/s horizontal and 20 m/s vertical wind uncertainty				No change from MSL.

Conclusions

- Without enhancements, EDL engineering constraints are almost identical to MSL constraints
- Landing site elevation capability improved by 2020 opportunity
  - But all other things being equal, lower is generally better
- Preliminary Mars Program future mission studies have not imposed any specific landing site constraints on Mars 2020
- Enhancements are feasible and provide significant landing site access improvement, but the project won't pursue them without direction
  - Even if enhancements become part of the baseline, will want to carry at least one "safe haven" site that satisfies MSL-like constraints